Time-based selection in complex displays: Visual Marking does not occur in Multi-Element Asynchronous Dynamic (MAD) search

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Abstract

In visual search, a preview benefit occurs when half of the distractor items (the preview set) are presented before the remaining distractor items and the target (the search set). Separating the display across time allows participants to prioritize the search set, leading to increased search efficiency. To date, such time-based selection has been examined using relatively simple types of search displays. However, recent research has shown that when displays better mimic real-world scenes by including a combination of stationary, moving and luminance-changing items (Multi-element Asynchronous Dynamic - MAD - displays) previous search principles reported in the literature no longer apply (Kunar & Watson, 2011). In the current work we examined time-base selection in MAD search conditions. Overall the findings illustrated an advantage for processing new items based on overall RTs but no advantage in terms of search rates. In the absence of a speed-accuracy trade-off no preview benefit emerged when using more complex MAD stimuli.

Introduction

People continually search the visual world. Using laboratory experiments, scientists have been able to study attentional mechanisms that enable people to filter out irrelevant information in order to prioritize more important stimuli. One example of such filtering has been uncovered using the *preview search paradigm* which has shown that observers are able to ignore currently visible information and direct their attention to new items that appear at a later point in time – time-based selection (Watson & Humphreys, 1997).

Watson and Humphreys (1997) investigated time-based selection by asking participants to search through items comprising of a conjuction of features to find a particular target. In their Full Element Baseline (FEB) participants searched for a blue H (target) among blue As and green Hs (distractors). They found that, similar to previous findings, people were relatively inefficient at searching through the display for a target item and produced relatively steep RT x set size search slopes (Treisman & Gelade, 1980). Importantly, in their experiment they also included a *preview condition* in which the same display was split into two parts. In this condition, participants first previewed half of the distractor items (green Hs) for 1000 ms. After this, the other half of the distractors (blue As) and the blue H target item were added to the display (the search set). Importantly, although the final display of the preview condition was identical to that of the FEB, search for the target was more efficient than in the FEB. Furthermore, search in the preview condition was as efficient as when only the blue items (the search set) were presented alone. This improvement in search efficiency was termed the *preview benefit* and indicated that people were able to ignore old, irrelevant stimuli and instead pay attention to new stimuli that appeared in the display.

There have been several accounts proposed to explain why the preview benefit occurs. First, Watson and Humphreys (1997) suggested that the old items were inhibited or *visually marked* so that they did not compete with items presented at a later point in time.

Visual marking occurred in a top-down, resource limited fashion with the need for active attention (e.g., Emrich, Ruppel, Al-Aidroos, Pratt & Ferber, 2008; Kunar, Shapiro & Humphreys, 2006; Olivers & Humphreys, 2002; Braithwaite et al., 2005; Kunar, Humphreys & Smith, 2003a; Watson & Kunar, 2010; von Mühlenen, Watson, & Gunnell, 2013; Zupan, Watson, Blagrove, 2016). Second, Donk and Theeuwes (2001) argued that the luminance onsets associated with the presentation of the new items captured attention automatically and thus there was no role for the inhibition of pre-existing elements. Third, Jiang, Chun and Marks (2002) suggested that by presenting the old and the new items at different times they formed two temporally distinct groups and attention could be applied to either group. Finally, recent work has shown that inhibition of small numbers of old items might rely on visual work memory (VWM) processes with larger numbers using a different inhibitory mechanism (Emrich, Al-Aidroos, Pratt & Ferber, 2010; Dube, Basciano, Emrich & Aidroos, 2016). Several studies have since suggested that these different mechanisms most likely work together to produce the preview effect depending on the particular stimulus properties present (e.g., Kunar, Shapiro & Humphreys, 2006; von Mühlenen, Watson, & Gunnell, 2013).

To date, research investigating time-based selection using the preview benefit has considered conditions in which all of the display items were either stationary (e.g., Watson & Humphreys, 1997; Kunar et al., 2003a; Olivers & Humphreys, 2002) or moving (e.g., Kunar et al., 2003b; Watson & Humphreys, 1998; Watson, 2001). However, in the real-world, search often takes place in much more complex scenes that can contain both stationary items and moving items. Furthemore, items can appear and disappear through occlusion, scenes can contain many items, and one cannot always be certain of the exact shape or properties of the target object. For example, imagine a security guard searching through CCTV footage of a busy airport, looking for ‘someone carrying a large bag’. Here the scene is both busy, featurally complex and the target is not uniquely specified.

Recently, Kunar and Watson (2011) developed a Multi-element Asynchronous Dynamic (MAD) search display to investigate basic search principles in more complex displays which were designed to better mimic some aspects of search in the real world. MAD search displays contained a relatively large number of search items, some of which were stationary and some of which were moving. Furthermore, half of the items disappeared and re-appeared from view, by blinking/fading off and on during the trial and multiple targets were defined. The results showed that with this more complex display, very different search findings were found compared to what was expected based on findings from research using traditional search paradigms. For example, previous research suggested that search for a moving target should be relatively efficient (Abrams & Christ, 2003, Franconeri & Simons, 2003; McLeod et al., 1988). Pinto, Olivers & Theeuwes (2008) also found efficient search for a moving target among blinking distractor items (see also Pinto et al., 2006, for search tasks using other types of dynamic displays). However, in MAD search moving targets were found less efficiently than stationary targets (Kunar & Watson, 2011; Kunar & Watson, 2014). Furthermore, previous studies found that items exhibiting luminance onsets captured attention (Yantis & Jonides, 1984). However, in MAD search luminance onsets did not capture attention (Kunar & Watson, 2011; Kunar & Watson, 2014). Miss error rates were also high (30-40%), in comparison with standard laboratory based visual search tasks which usually produce relatively low rates (5-10%, Wolfe, 1998). It seems that with these more dynamic and complex scenes, search principles that have been inferred from previous work no longer hold.

The main aim of the present work was to determine to what extent time-based selection is effective in MAD search conditions which we assessed using the preview search paradigm. On the one hand we might expect that a preview benefit will occur because previous work has demonstrated the existence of a solid preview benefit with both stationary (e.g., Watson & Humphreys, 1997) and moving (Watson & Humphreys, 1998; Watson, 2001, Kunar et al., 2003) stimuli. On the other hand given that many ‘standard’ search principles do not seem to hold with MAD displays we might expect that the efficiency of preview search would also be compromised.

The vast majority of previous preview studies have typically used relatively standard set sizes of up to 16 items (but see Jiang, Chun, & Marks, 2002a). However, the work on MAD search has used larger set sizes of between 16 to 32 items. Therefore in the present work we assessed preview search in both low (4, 8, 16 items) and high (16, 24, 32) density displays. Experiments 1a and 1b presented MAD displays in which the target was either present or absent (as in Kunar & Watson, 2011, 2014). Experiments 2a and 2b used a target discrimination task in which the target was always present. Experiments 1a and 2a used low density displays Experiment 1b and 2b used high density displays.

Experiment 1a and 1b: Target Present-Absent MAD Preview Search

Method

Participants

Forty-nine participants (thirty-one women), aged 18 to 35 years (*M* =21.31, *SD*= 3.5) were recruited from the University of Warwick. All participants had normal or corrected to normal vision. Twenty-four participants (14 women) completed Experiment 1a and twenty-five participants (17 women) completed Experiment 1b.

Stimuli and procedure

Displays were generated and responses recorded by custom written computer programs. Stimuli were white letters of the alphabet (average luminance 14.9 cd/m^2,) displayed on a black background (Figure 1). Participants were asked to search for a letter vowel (A, E, I, O, or U) amid distractor consonant letters (W was omitted because it was wider than the other consonants). The target was present on 50% of trials. When present, the target was equally likely to be any of the five vowels and only one target was presented per trial, following previous MAD methodology (Kunar & Watson, 2011).

Figure 1 about here

In each display, 50% of the items were stationary. The other 50% moved randomly in any direction, passing over one another transparently and rebounding off the edges of an invisible box (14.5 degrees x 14.5 degrees). Moving items were randomly assigned speeds between 1.9 and 3.3 degrees/second (from a viewing distance of 57 cm). Across the stationary/moving items, half of the stimuli changed luminance as well, such that they faded gradually and continually between a luminance value of 38.2 cd/m^2 and 0.7 cd/m^2 and back again over 1-3 seconds without ever completely offsetting. The luminance changes were out of phase preventing stimulus grouping based on synchronized luminance changes. Items continued moving and/or blinking until participants responded. The target was equally likely to be moving and/or blinking.

There were two experimental conditions – the *FEB* condition and the *preview* condition. In the FEB condition, participants were presented with a central fixation dot for 1000ms before all the search stimuli were presented simultaneously. In the preview condition, participants were presented a fixation dot for 1000ms followed by half of the distractors for 1000ms. After this time the remainder of the distractors and the target (when present) were added to the display. Participants were asked to indicate if the target was present or absent by pressing the letter *m* for target present trials or *z* for target absent trials as quickly but as accurately as possible. The search display remained visible until participants responded or until a time-out of 10s had elapsed. Participants completed 240 FEB trials and

240 preview trials. Reaction times (RTs) and error rates were recorded. No feedback was given for either correct or incorrect responses. Participants were given a block of practice trials before each condition.

Results

Trials with RTs shorter than 200ms or longer than 10s were removed as outliers (less than 0.2% of the data). Figure 2 shows the mean correct RTs for all conditions. RTs for correct trials were entered into a mixed 2 (Condition: FEB vs Preview) x 2 (Target presence: Present vs Absent) x 3 (Set Size: Number of display items) [1] x 2 (Density: low vs high) ANOVA with Density as a between-subjects factor and the remainder as with-subject factors.

All four main effects were significant; RTs were shorter in the preview condition than in the FEB condition, $F(1,47) = 16.7$, $p<.01$; were shorter when the target was present than when it was absent, $F(1,47) = 221.3$, $p<.01$; were shorter overall in the low density condition than in the high density condition, $F(1,47) = 34.7$, $p<.01$, and increased with set size, $F(2,94) = 250.4$, $p<.01$. All the two-way interactions with Density were significant (all *F*s > 12, *p*s<.01) apart from the Condition × Density interaction ($F<1$). Unsurprisingly, there was a significant Target presence × Set-size interaction, $F(2,94) = 111.4$, $p<.01$; RTs increased more with set size on target absent trials than on target present trials. There was also a significant Condition × Target presence interaction, $F(1,47) = 12.7$, $p<.01$; the difference between target present and absent trials was greater in the FEB condition than in the Preview condition. Of most interest was a significant Condition × Set Size interaction, $F(2,94) = 9.4$, $p<.01$; RTs increased more with increasing set size in the FEB condition than in the Preview

[1] For this analysis we treated the three set-sizes of the low density (4, 8, 16 items) and high density (16, 24, 32 items) conditions as equivalent levels of a single factor.

condition, illustrating the presence of a preview benefit. The three way Target x Set size x Density interaction was significant, $F(2, 94) = 3.3$, $p < 0.05$. As there was a significant three-way Condition × Set Size × Target presence interaction, $F(2,94) = 4.3$, $p<.05$, we analysed the data in two further ANOVAs, with factors of Condition × Set Size × Density for absent trials and present trials respectively. None of the other three way or four way interactions were significant (all Fs < 1.4, ps > 0.2).

Absent trials. There was a main effect of Condition, $F(1,47) = 16.2$, $p < .01$, Density, $F(1,47) = 30.9$, $p < .01$, and Set-size, $F(2,94) = 206.7$, $p < .01$; RTs were shorter in the preview condition, shorter in the low density condition and increased with set-size. There was a significant Set Size × Density interaction, $F(2,94) = 8.7$, $p < .01$; RTs increased more across set size in the High density condition compared to the Low density condition. Of most interest was a significant Condition × Set Size interaction, $F(2,94) = 9.0$, $p < .01$; RTs increased more with set size in the FEB condition compared to the Preview condition, indicating a preview benefit. Neither the Condition × Density interaction ($F < 1$), nor the three-way interaction, $F(2,94) = 1.4$, $p = 0.26$, were significant.

Present trials. There was a significant main effect of Condition, $F(1,47) = 14.9$, $p < .01$, Density, $F(1,47) = 37.4$, $p < .01$, and Set size, $F(2,94) = 220.9$, $p < .01$. RTs were shorter overall in the preview condition, shorter overall in the Low density condition, and increased with Set size. There was also a significant Set Size × Density interaction, $F(2,94) = 19.2$, $p < .01$; RTs increased more across set size in the High density condition compared to the Low density condition. Importantly, the Condition × Set Size interaction was significant, $F(2,94) = 3.2$, $p < .05$; RTs increased more with set size in the FEB condition than in the Preview condition, indicating the presence of a preview benefit. Neither the Condition × Density, nor the three-way interaction were significant (both Fs < 1).

Figure 2 about here

Error rates for all conditions are shown in Tables 1 and 2. A mixed analysis of variance (ANOVA) on percentage error rates showed that all four main effects were significant. The overall error rate was greater in the preview condition than the FEB condition $F(1,47) = 4.7$, $p < .05$, on present than on absent trials, $F(1,47) = 96.6$, $p < .01$, and in the High density condition than the Low density condition, $F(1,47) = 4.6$, $p < .05$. Errors also increased as set size increased, $F(2,94) = 21.6$, $p < .01$. The Target presence x Set size interaction was also significant, $F(2,94) = 14.8$, $p < .01$; errors increased more over set size for target present trials compared to target absent. However, of most relevance was a significant Condition x Set Size interaction, $F(2,94) = 3.5$, $p < .05$; errors increased more with set size in the preview condition than in the FEB condition. No other interactions reached significance (all *F*s < 3.7, *p*s > 0.05).

Tables 1 and 2 about here

Discussion

The main aim of Experiment 1 was to determine the effectiveness of time-based selection under MAD search conditions. In terms of search efficiency the results were somewhat mixed. The significant Condition × Set Size interaction in both the RT and the error rate data suggests the presence of a speed accuracy trade-off. RTs increased less with set size in the preview condition compared to the FEB but errors increased more. One possible reason why miss errors were comparatively high is that participants adopted a relatively conservative search strategy. That is, in this complex search task when participants were uncertain if the target was there or not they were biased to respond absent after an incomplete search of the display (see also Chun & Wolfe, 1996). If high miss errors are due to a conservative search strategy, then we would expect that they should reduce in MAD search when it is known that the target is always present. Removing this speed-accuracy trade-off will give us better insight as to whether a preview benefit occurs in these more complex search environments. Accordingly, to address this issue in Experiments 2a and 2b we used a discrimination task in which the target was always present rather than a present-absent task.

Experiment 2a and 2b: Target Discrimination in MAD Preview Search

Method

Participants

Forty-two participants (twenty-six female) aged 18 to 25 (*M* =20.5, *SD*= 1.4) were recruited from the University of Warwick. All participants had normal or corrected-to-normal visual acuity. Twenty-six participants (17 female) completed the low density condition and 16 participants (9 female) completed the high density condition.

Stimuli and procedure

The stimuli and procedure were similar to those of Experiment 1 except that all stimuli were surrounded by the outline of a white box (1.2° x 1.2°) which had a small gap (0.2°) midway on either the left or right side. The boxes remained visible throughout the display and did not blink on and off. However, they moved with the targets and distractors if the stimuli were moving. Participants were asked to report whether the placeholder around the target vowel had a gap in it to the right or the left by pressing the *m* key or the *z* key respectively. Previous work has shown that the addition of placeholders to the display does not interfere with MAD search (Kunar & Watson, 2011). Unlike Experiment 1, the target was present on all trials. Participants completed 240 full element baseline trials and 240 preview trials.

Results

RTs shorter than 200ms or longer than 10s were removed as outliers (less than 0.3% of the data). Mean correct RTs are shown in Figure 3. The data were analysed using a mixed 2 (Condition: Preview vs FEB) × 3 (Set-size) × 2 (Density: High vs Low) ANOVA, with Condition and Set-size as within-subject factors, and Density as between-subject. All three main effects were significant. RTs were shorter overall in the preview condition than the FEB condition, $F(1,40) = 20.4$, $p < .01$, were shorter in the Low density than the High density displays, $F(1,40) = 21.8$, $p < .01$, and increased with set-size, $F(2,80) = 326.3$, $p < .01$. There was a significant Set Size x Density interaction, $F(2,80) = 9.7$, $p < .01$; RTs increased more across set size in the High density condition compared to the Low density condition. However, of most interest, the Condition × Set Size interaction was not significant, $F(2,80) = 2.2$, $p = 0.12$, providing no evidence of a preview benefit. No other interactions were significant (all Fs>1.1, ps < 0.3).

Figure 3 about here

Examining error rates (Tables 1 and 2) showed that overall, errors increased with set-size, $F(2,80) = 7.4$, $p < .01$. However, there was no main effect of Condition, $F(1,40) = 2.3$, p

= 0.14, nor of Density, $F(1,40) = 1.3$, $p = 0.26$. None of the interactions were significant (all Fs < 1, ps > 0.4).

Discussion

The main aim of Experiment 2 was to examine time-based selection in MAD search conditions when the target was always known to be present in the field. We predicted that by providing a clear end point to search (because the target was always present) target-miss error rates should be substantially lower than those of Experiment 1. With regard to this point, there was a clear reduction in the number of errors made, from 16.9% in Experiment 1 to 3.5% in Experiment 2. Hence, as predicted, having the target present on all trials led to a less conservative search strategy. However, of most interest was the extent to which a preview benefit occurred in these low miss-error rate conditions. Considering the search slopes, there was no evidence at all for a reliable difference in the slopes between the preview and FEB conditions. Nevertheless, as in Experiment 1, there was a reliable difference in overall RTs between the preview and FEB conditions; with shorter RTs in the preview condition than in the FEB condition.

General Discussion

Previous work has shown that people are able to prioritize the selection of visual stimuli such that old, irrelevant objects can be ignored or suppressed, and new stimuli prioritized – the preview benefit. This benefit has been shown to occur using a wide range of stimuli (e.g., Watson & Humphreys, 1997; Watson & Humphreys, 1998; Kunar et al., 2003b; Kunar & Humphreys, 2006; Osugi et al., 2010; Fenske et al., 2004). In the current work we examined whether such time-based selection is possible in more complex MAD search displays which better mimic the properties of searches that are likely to take place in real-world tasks and settings. Of note, previous work has shown that many established search principles do not hold in MAD displays and so it is important to establish whether time-based selection is also compromised in such displays. Our results showed that in the absence of a speed-accuracy trade off a preview effect did not occur in MAD search.

Before we consider the results further, it is worth considering how the present study links with previous findings of the preview benefit in terms of motion changes. A robust preview benefit has been shown with both stationary stimuli (e.g., Watson & Humphreys, 1997), and moving stimuli (Watson & Humphreys, 1998; Watson, 2001). With stationary stimuli it does not seem to matter whether there is a feature difference (such as color) between the old and the new stimuli (Theeuwes, Kramer & Atchley, 1998, Olivers, Watson and Humphreys, 1999, Kunar et al., 2003, but see also Donk, 2017). However, with moving stimuli the picture is more complex. Watson and Humphreys (1998) showed that a robust preview benefit occurred with linearly moving, wrap-around displays in which stimuli were presented behind a virtual window. That is, stimuli moved down the screen and when they reached the bottom of a window they scrolled off bit-by-bit and then re-emerged at the top of the window bit-by-bit. Kunar et al. (2003) showed similar results in a condition where the moving stimuli never disappeared from the display but simply changed their direction on reaching the edge of the screen. Importantly, in both these experiments the old-previewed stimuli were green and the new stimuli were blue. When a similar experiment was run with monochromatic stimuli (Olivers, Watson and Humphreys, 1999) there was no preview benefit. Watson and Humphreys (1998) proposed that for a preview benefit to occur in these displays moving stimuli were suppressed via the application of inhibition at the level of object features (e.g., a feature map, see also Kunar et al., 2003).

However, Watson (2001) showed later that a preview benefit could be obtained even with moving stimuli that were all the same color provided that the local spatial relationships remained constant. This was examined by using displays that rotated globally around the center of the screen. With this type of motion, the absolute position of the stimuli change but their relative locations do not. Watson (2001) suggested that this relative position constancy allowed the visual system to develop a spatial template of the preview items which was linked to a rotational transform and allowed inhibition to be maintained on the previewed items (see also Kunar, Humphreys, Smith & Hulleman, 2003). With linearly moving, wrap-around displays, this was not possible because the relative spatial relationships between the old stimuli in the preview display were not constant over time. Thus a fixed spatial representation of the old items could not be developed.

Given this, what might we expect in terms of MAD search performance? On the one hand, in MAD search, the preview items did not maintain fixed relative positions. That is, half the preview items were moving in different directions at different velocities and changed direction at different times. In addition, half of the preview items were stationary. Therefore, based on the findings from Watson (2001) and Olivers, Watson and Humphreys (1999) we might expect that the full set of old/preview stimuli would not be able to be ignored. This is because it would not be possible to develop a spatially stable representation in order to co-ordinate the application of inhibition to the previewed items. However, an alternative explanation for why linearly moving, monochromatic wrap-around displays did not produce a preview benefit in Olivers, Watson and Humphreys (1999) is that when items re-appeared at the top of the virtual window they were perceived as perceptually new objects (Yantis & Gibson, 1994). This could have then abolished any inhibition applied to those items, just as an identity altering shape change to a previewed item also causes those items to re-compete for attention (Watson & Humphreys, 2002; Osugi et al., 2010, Kunar & Humphreys, 2006). Thus, it remains possible that moving preview stimuli can, in fact, be successfully suppressed even if their relative spatial locations change, provided that they do not change in a way that suggests they become perceptually new objects during the preview period.

Of note, in the MAD displays presented here, unlike with wrap-around displays, none of the old items ever completely disappeared and re-appeared somewhere else. Hence there was no opportunity to perceive the previewed items as forming perceptually new objects throughout the preview period. It is thus possible that we could have obtained a robust and full preview benefit in the MAD search conditions. In addition, half of the display items were stationary in our MAD preview display and hence we might also expect that these old *stationary* items could still be suppressed because they maintained a fixed position in space. If this were the case, then we would expect to find at least partial preview benefit with approximately a quarter of the display items being suppressed. However, the findings were not consistent with either of these two possibilities with no evidence to support the existence of even a partial preview benefit.

Explaining the lack of a preview benefit: Theoretical Implications

Theoretically, the results can be explained by the luminance onset capture, temporal grouping and the visual marking account of the preview benefit. According to the onset capture account new items are prioritized because the luminance onsets generated by their appearance capture attention automatically (Donk & Theeuwes, 2001, Agter & Donk, 2005; Belopolsky, Theeuwes, & Kramer, 2005; Donk, 2006; Donk & Theeuwes, 2001, 2003; Donk & Verburg, 2004). In the present work, having transient displays in terms of moving and blinking stimuli in the preview display could lead to a masking of the luminance onsets produced by the appearance of the new items. This would lead to a reduction of the preview effect. The temporal grouping account (Jiang, Chun, & Marks, 2002a) likewise might explain the lack of preview effect if the presence of the moving and blinking stimuli disrupted the ability to temporally group the displays into old and new sets. The current data do not refute either the onset or the temporal grouping accounts. However, note that for these accounts we would have to make a couple of assumptions. Specifically, we would have to assume that the gradual and continuous fading of the 'blinking' stimuli and/or the motion of the moving stimuli produced sufficiently strong luminance-change signals to compete with the abrupt luminance onsets associated with the onset of the new items (at previously empty locations).

The data can also be explained by the inhibitory visual marking account (Watson & Humphreys, 1997). In respect to this account one possibility is that that the changes in luminance and motion of the preview items continually attracted attention and this interfered with the development of an inhibitory template for even the stationary items. Another possibility is that developing an inhibitory template towards the previewed items in more complex displays takes longer than the 1000ms allowed in the present work. Earlier work suggested that with stationary stimuli, a preview duration of approximately 400ms is needed to obtain a full preview benefit (e.g., Watson & Humphreys, 1997). In contrast, when the locations of the stimuli were more difficult to encode (as is the case with stimuli that are iso-luminant with their background) a longer preview duration (3000ms) was needed for a preview benefit to emerge (Braithwaite, Hulleman, Watson & Humphreys, 2006). If, as seems likely, coding and tracking the locations of stimuli in MAD search conditions is more difficult than in simpler displays, it is possible that a preview benefit might emerge even in MAD search conditions if a longer preview duration was available.

It is also possible that the lack of preview benefit with MAD displays represents a strategic decision to intentionally not apply inhibition to the old items. According to the inhibitory visual marking account participants can apply or withhold inhibition in a flexible manner depending on task goals (Watson & Humphreys, 2000). Recent work using relatively simple displays (Zupan, Watson & Blagrove, 2015), showed that participants will by default intentionally supress irrelevant stimuli in the preview period when looking for new items. However, there was also evidence that they reduced the extent to which they would inhibit previewed items when there was little benefit to be gained on the majority of trials. In the present work there would be a clear benefit to suppressing the previewed stimuli given the difficulty of the search. However, it is possible that the perceived effort involved in suppressing stimuli in the more complex MAD search conditions biased people away from applying inhibition. In this way participants might have strategically withheld the application of inhibition. The current data cannot separate these differing possibilities but it would be worth establishing whether strategic choice, timing or capacity limitations account for the lack of successful time-based selection in MAD search conditions.

Search slopes versus overall RTs

The best indicator of the extent to which old stimuli can be de-prioritized is based on search slopes as this indicates the number of items considered during the search process. However, in both experiments we did find an overall reduction in RTs in the preview condition relative to the FEB condition. Thus although there was no slope-based preview benefit, there was nonetheless an advantage in terms of the overall time it took participants to respond correctly (see also Humphreys et al., 2004, for examples of preview benefits based on overall RTs). Given the present set-up it is difficult to determine the exact cause of this overall benefit. One possibility is that the preview display acted as a warning signal for the onset of the search display (see Watson & Humphreys, 1997, for further discussion of this possibility). Another possibility is that a fixed and small number of preview items could be inhibited (perhaps via a VWM inhibitory mechanism; Emrich, Al-Aidroos, Pratt & Ferber, 2010) which reduced the number of items searched in the preview condition by a fixed number. Either way the present results suggest a small overall preview advantage but provide little evidence for the exclusion of multiple preview items typically observed in earlier preview studies. For now, however, as was the case for other established search principles, our data suggest that time-based selection might not be as effective in real-world conditions as might be expected from prior research. Determining the exact cause of the compromised time-based selection in MAD search conditions (either capacity or strategic) will be a useful goal for future work.

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Table 1. Percentage of errors as a function of condition and set size (ss) for the Low Density conditions of Experiments 1a and 2a

Condition	Absent Errors (%)			Present Errors (%)		
	ss8	ss12	ss16	ss8	ss12	ss16
Experiment 1a – FEB	1.4	1.0	1.1	10.9	15.4	13.9
Experiment 1a - Preview	1.2	0.6	1.2	11.1	13.8	16.7
Experiment 2a – FEB	n/a	n/a	n/a	3.3	3.4	4.3
Experiment 2a - Preview	n/a	n/a	n/a	4.2	3.6	4.7

Table 2. Percentage of errors as a function of condition and set size (ss) for the High Density conditions of Experiments 1b and 2b

Condition	Absent Errors (%)			Present Errors (%)		
	ss16	ss24	ss32	ss16	ss24	ss32
Experiment 1b – FEB	0.9	1.3	2.0	14.5	19.6	20.1
Experiment 1b – Preview	1.4	2.7	4.7	17.2	23.1	25.5
Experiment 2b – FEB	n/a	n/a	n/a	1.7	2.4	3.4
Experiment 2b - Preview	n/a	n/a	n/a	2.9	2.4	4.2

Figure Captions

Figure 1. Example displays for the Preview condition of Experiment 1. The FEB condition was identical but without the Preview screen. Arrows represent moving items. Stimuli surrounded by stars represent items that fade on and off. The target (if present) was a vowel.

Figure 2. Mean RTs for Experiment 1a and 1b as a function of set-size and condition. FEB = Full-element baseline, PRE = Preview, Low = Low density (8 to 16 items), High = High density (16 to 32 items). Search slope values (in ms/item) are shown in the parentheses.

Figure 3. Mean RTs for Experiment 2a and 2b as a function of set-size and condition. FEB = Full-element baseline, PRE = Preview, Low = Low density (8 to 16 items), High = High density (16 to 32 items). Search slope values (in ms/item) are shown in the parentheses.

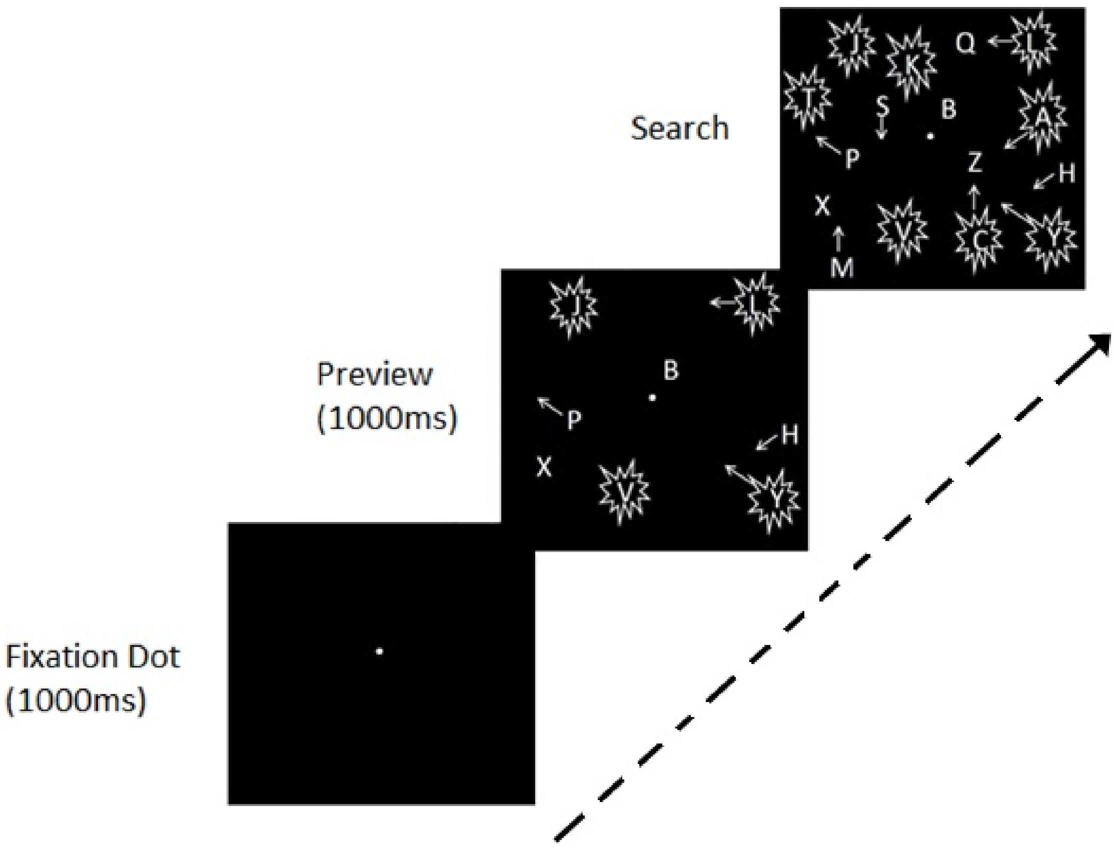
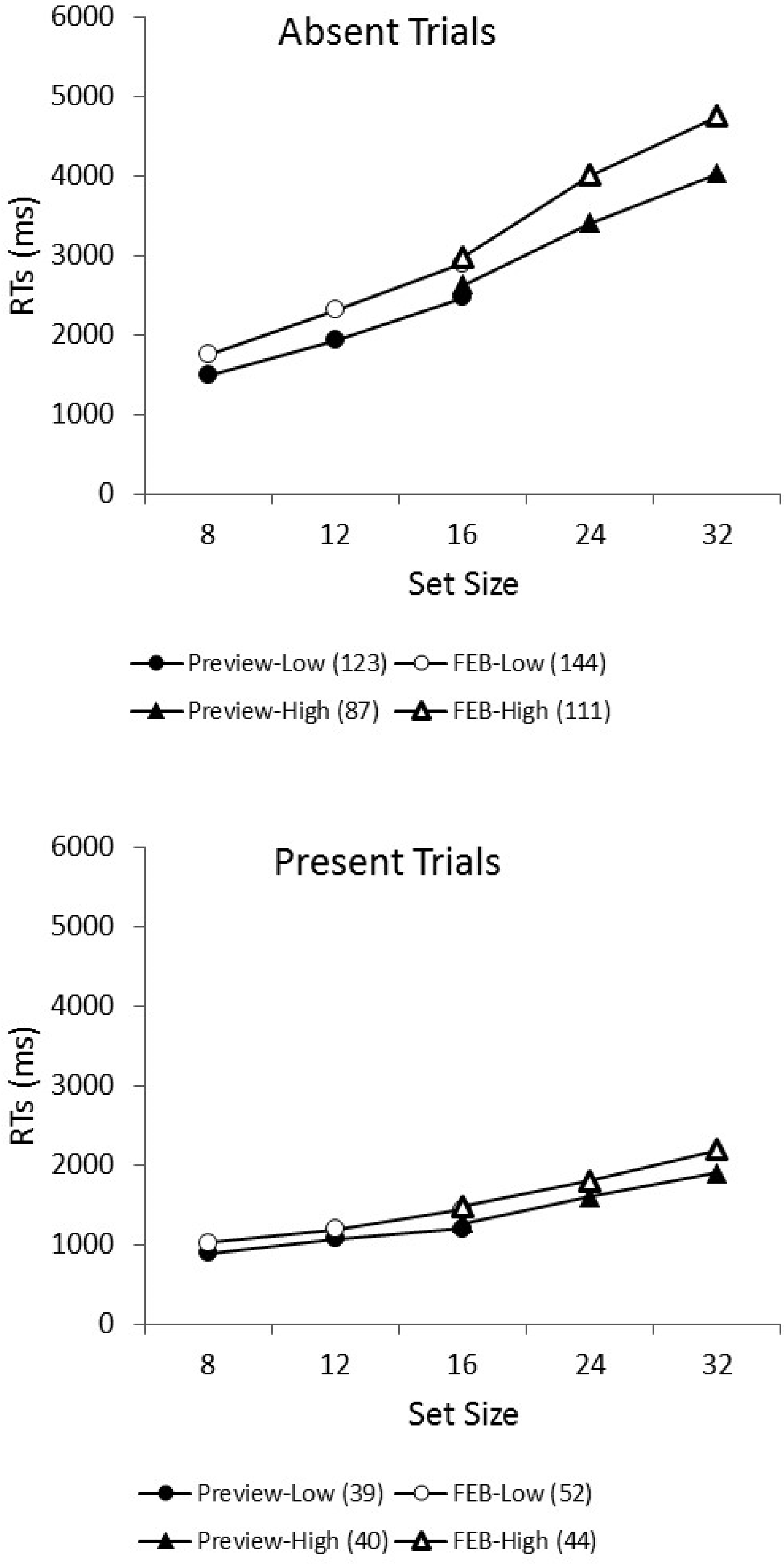


Figure 1



Absent Trials
6000
5000
4000
3000
2000
1000
0
RTs (ms)
8
12
16
24
32
Set Size
Preview-Low (123)
FEB-Low (144)
Preview-High (87)
FEB-High (111)
Present Trials
6000
5000
4000
3000
2000
1000
0
RTs (ms)
8
12
16
24
32
Set Size
Preview-Low (39)
FEB-Low (52)
Preview-High (40)
FEB-High (44)

Figure 2

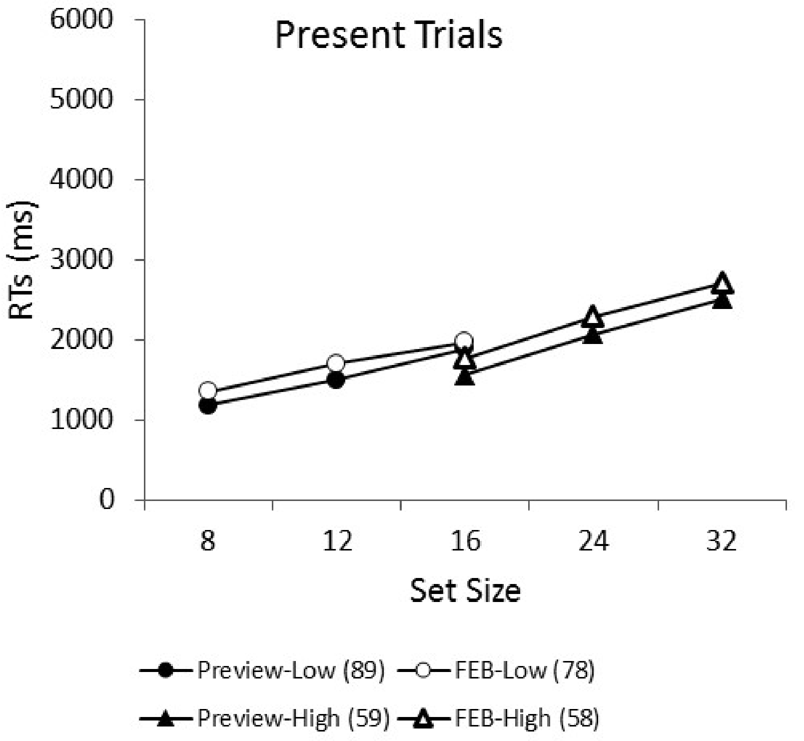

Present Trials
6000
5000
4000
3000
2000
1000
0
RTs (ms)
8
12
16
24
32
Set Size
Preview-Low (89)
FEB-Low (78)
Preview-High (59)
FEB-High (58)

Figure 3